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CDF and D0

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Bill Carithers

*Lawrence Berkeley Laboratory
Berkeley, California*

*Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510*

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New W mass results from CDF and D0

Bill Carithers

Lawrence Berkeley National Laboratory
On behalf of the CDF and D0 collaborations
E-mail: carithers@fnal.gov

Abstract

This article describes recent measurements of the W mass by the CDF and D0 Collaborations. CDF obtains a preliminary result of 80.473 ± 0.113 GeV for the W mass in the electron channel and D0 reports a preliminary result of 80.691 ± 0.227 GeV for electrons in the more forward (Endcap) rapidities. When combined with all previous measurements, the current average for the W mass measured at the Tevatron is 80.452 ± 0.063 GeV.

1. Introduction

The W mass measurement is a direct and stringent test of the Standard Model. The value at tree level is precisely predicted and loop corrections are sensitive to the square of the top mass and the logarithm of the Higgs mass. Just as precise EWK measurements gave indirect evidence for a top mass near 175 GeV before the top was discovered, precise measurements of the W mass will either give some indication of the Higgs mass or a signal for new physics.

The recent Tevatron run was divided into two periods, usually denoted Run Ia (1992-93) and Run Ib (1994-95). Both CDF and D0 have published [1] W mass results from Run Ia and achieved a combined uncertainty of 150 MeV. Using the higher statistics from Run Ib (90 pb^{-1}), D0 has published [2] results based on W decays to the electron channel in the central region, $|\eta| < 1$. CDF has presented preliminary results [4] for W's decaying in the muon channel.

This paper describes two new results and combines all previous Tevatron measurements into the current best average. D0 has augmented their analysis by extending the electron pseudorapidity coverage into the endcap region, $1.5 < |\eta| < 2.5$ [3]. CDF has completed the analysis in the electron channel and improved the systematic uncertainty in the muon channel.

2. Measurement technique

The hadron collider environment imposes many restrictions on the detectors and consequently on experimental observables. One of the most important of these is a

restricted rapidity coverage so that longitudinal momentum conservation is no longer a useful constraint. Consequently, the W mass analysis uses the transverse components of momentum and energy. Moreover, the neutrino from W decays is not directly detected but inferred from the missing transverse energy, \cancel{E}_T , required to conserve momentum in the transverse plane. The most useful measure of the W mass is the transverse mass (M_T), the two-dimensional analogue of the invariant mass, since this quantity is independent of the W P_T to first order. The transverse mass is given by

$$M_T = \sqrt{2P_T^l \cancel{E}_T (1 - \cos \phi)}$$

where ϕ is the angle between $\vec{\cancel{E}}_T$ and \vec{P}_T^l .

It is also convenient to split $\vec{\cancel{E}}_T$ into two components, the (dominant) lepton transverse momentum and a (usually small) recoil term, \vec{U} :

$$\vec{\cancel{E}}_T = -(\vec{U} + \vec{P}_T^l)$$

The recoil term contains contributions from QCD initial state radiation and from any additional $\bar{p}p$ interactions that occur in the same beam crossing as the W production. These are treated in more detail in section four.

3. Energy scale

Any error in the energy/momentum scale of the lepton enters directly in the W transverse mass. Both CDF and D0 use the Z mass reconstructed from leptonic decays to set the scale. The scale is adjusted until the Z mass agrees with the very precise value from LEP. In that

sense, both collaborations actually measure the ratio of the W and Z masses.

Specifically, D0 assumes that the observed E_T is given by a scale factor which multiplies the true E_T plus an offset term. The scale factor and offset are determined by simultaneous fits to the Z mass as a function of the Z boost, to the J/ψ mass from $J/\psi \rightarrow e^+e^-$ decays, and to π^0 double-Dalitz decays [1]. CDF uses the Z mass in $Z \rightarrow \mu^+\mu^-$ decays to set the momentum scale. Any non-linearities in the momentum scale are limited by measuring the Z mass, the Υ mass from $\Upsilon \rightarrow \mu\mu$ decays, and the J/ψ mass also from $\mu\mu$ decays, all as a function of track curvature. The electron energy scale is set by the Z mass in $Z \rightarrow e^+e^-$ decays. A small non-linearity in the electron energy measurement is determined by measuring the ratio of electron transverse energy to transverse momentum, E/p , as a function of E_T in the high-statistics $W \rightarrow e\nu$ sample and in the Z sample. Parenthetically, CDF also attempted an absolute scale measurement based on E/p but this was abandoned when the simulation was not adequate to reproduce the correct value for the Z mass.

Both CDF and D0 use the line shape of the Z mass to determine the lepton energy resolution which enters directly in the fits to the M_T^W distribution for the W mass.

4. W production model

The details of how the W is produced enter the mass measurement in two ways. First, in the transverse direction any P_T^W will boost the P_T^l and \cancel{E}_T distributions and enter directly when these distributions are fit for the W mass. The transverse mass is less sensitive but P_T^W effects do enter at higher order. In the longitudinal direction, the W rapidity would be irrelevant if the detectors had full coverage. With limited coverage, the shape of the M_T^W distribution would be biased if the W production were not well-modelled.

The W P_T distribution is determined by measuring the Z P_T distribution in leptonic decays where the resolution is very good and then appealing to the theoretically well-known ratio of W to Z production. The uncertainty is entirely limited by the statistics of the Z sample.

The Z sample is also used to understand how the detectors respond to the recoil energy when the W is produced with appreciable P_T as noted earlier in the discussion of \cancel{E}_T . The recoil measured by the calorimeters is compared to the Z P_T . The recoil component transverse to the Z direction is unbiased and shows a resolution expected from minimum bias events. The recoil component $U_{||}$ parallel to the Z direction is influenced by jets in the event and typically shows a poorer resolution and a bias, $\langle U_{||} - P_T^Z \rangle$. This bias enters as a correction in modelling the W recoil. The uncertainties are limited by the Z statistics and translate

typically to an uncertainty in the W mass of about 25-40 MeV.

The W rapidity distribution is determined by the parton distribution functions (PDF). The W mass is sensitive to any differences in the momentum fraction carried by the up quark compared to the down quark. Experimentally, the up quark does carry a larger fraction of the proton momentum and this leads to a charge asymmetry in the W production. Specifically, the $W^{+(-)}$ is produced preferentially along the $p(\bar{p})$ direction. CDF has measured the charge asymmetry [5] as a function of rapidity, and both CDF and D0 use this measurement to constrain the systematic uncertainty due to the PDF's.

5. Mass fits

To fit for the W mass, a full simulation is used to generate templates of the M_T^W at discrete values of the W mass and width. These simulations include backgrounds, W production details, detector resolutions, and detector responses as described above. A maximum likelihood fit for data comparisons with the templates gives the most likely value of mass and width. Having shown that the best fit value for the width is compatible with the Standard Model prediction, the data are re-fit for the mass with the width fixed at the Standard Model value. The fits for the D0 endcap data and the CDF muon and electron data are shown in Figure 1.

The P_T^l and \cancel{E}_T distributions can also be fit for the W mass. As discussed above, these distributions are more sensitive to P_T^W . They are very highly correlated with the M_T distribution but do contain some independent information. D0 uses this information to reduce the systematic uncertainties somewhat, while CDF uses the P_T^l and \cancel{E}_T fits only as consistency checks.

The uncertainties are shown in Table 1. In this table, the uncertainty labelled 'statistical' refers only to the uncertainty in the maximum likelihood fits to the M_T^W templates. We emphasize that, although the remaining uncertainties are usually considered 'systematic', they are in fact determined by the statistics of ancillary data sets.

6. Conclusions

Both CDF and D0 have reported new measurements of the W mass. When combined with previously published values, D0 reports a value of 80.482 ± 0.091 GeV and CDF obtains 80.433 ± 0.079 GeV. The combined Tevatron average is then 80.452 ± 0.063 GeV where a common systematic error of 25 MeV includes the highly correlated PDF's and QED corrections. For the first time, both collaborations have reduced the total error below 100 MeV and the combined Tevatron average is comparable to the combined LEP II results. Taken

Error source	D0(EC)	CDF(e)	CDF(μ)
Statistical	108	65	100
Lepton (E,p) scale	188	75	85
P_T^W and recoil	52	40	40
Detector resolution	46	25	20
PDF	17	15	15
Backgrounds	20	5	25
other systematics	11	20	21
Total error	227	113	143
Mass value(GeV)	80.691	80.473	80.465
Combined mass(GeV)	$80.498 \pm .095$	80.470 ± 0.089	

Table 1. Summary of uncertainties (in MeV). The D0 combined value includes the Run Ib data from the central region.

together, the Tevatron plus LEP II results still prefer a light Higgs mass [6].

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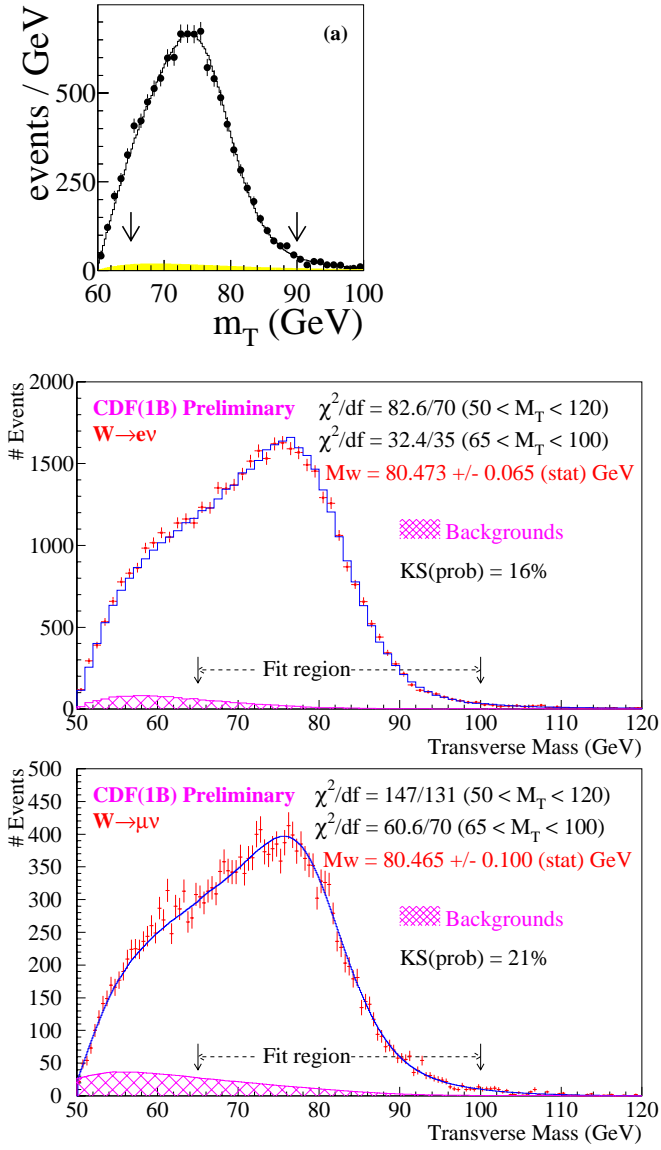


Figure 1. Transverse mass distributions compared to the best fit. TOP : D0 endcap analysis, MIDDLE: CDF electron channel, BOTTOM: CDF muon channel analysis.